SOURCE
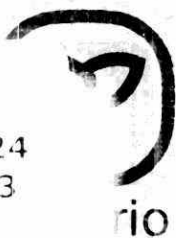# TESTING
CODE

Ministry
of the
Environment

rio

The Honourable
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Minister

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MINISTRY OF THE ENVIRONMENT, PROVINCE OF ONTARIO

AIR MANAGEMENT BRANCH

SOURCE TESTING CODE

Report #

ARB-TDA-39-80

JANUARY 1973

A   CODE

Ministry of the Environment, Province of Ontario, Air Management Branch Source Testing Code for Determining the Concentrations of Particulate and Gaseous Pollutants in Confined Gas Streams.

B   PURPOSE

A recommended source testing code with appropriate flexibility to permit consistent and accurate determinations of particulate and gaseous pollutant concentrations before and after air cleaning equipment in ducts and stacks of chemical, metallurgical and combustion processes. The source testing code should be used when obtaining emission information for the Air Management Branch. Sampling methods for pollutants not mentioned in the Code and any deviations from the recommended sampling procedures, equipment and methods of analysis should be reviewed with the Air Management Branch prior to conducting source sampling tests.

C   PERSONNEL

1.   Normal Size Sampling Team

A source sampling team, under the direction of the source testing supervisor, shall consist of no less than two persons to measure the concentrations of the pollutants at the sampling site and to record the data collected.

When sampling the emissions from a continuous, steady process, it shall be the responsibility of the source sampling team leader to obtain data detailing the process production rates and operating conditions over the entire sampling period.

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When sampling the emissions from a cyclic, batch or charging process, a third sampling team member shall be required to obtain data detailing the process production rates and operating conditions while the sampling is taking place. This person shall inform the two persons at the sampling site of any changes or upsets in the process production rates and conditions so that appropriate changes can be made in the sampling procedure.

2.   Desirable Qualifications of Normal Sampling Team

The following qualifications are intended as a guide for selecting people to conduct source sampling tests.

The source testing supervisor should have a relevant degree, or the equivalent of such a degree, (e.g. chemical, mechanical or environmental engineering) or at least one year's experience supervising source testing. The source testing supervisor shall be responsible for all aspects of the source test.

The remaining sampling team members should have a diploma, or the equivalent of a diploma, from a chemical, mechanical or environmental program in a College of Applied Arts and Technology, or at least six months of source sampling experience.

Those team members who have a relevant degree, the equivalent of such a degree, or a diploma, but no previous source sampling experience, should undergo a two-week lecture and laboratory training program (part of this training could be obtained by attending an Air Management Branch approved source sampling school and the remainder could be obtained in the firm's own facilities) followed by two weeks of source sampling in the field before

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qualifying as part of any source sampling team.

D   PRE-TEST INFORMATION

1.   Responsibility

The collection and evaluation of the pre-test information prior to the source sampling tests shall be the responsibility of the source testing supervisor.

2.   Source Process Information

Before any source sampling tests are carried out, the source testing supervisor shall become familiar with the pertinent operating characteristics of the process whose emissions are to be sampled. These operating characteristics should include but are not limited to:

(i)   mode of process operation (cyclic, batch charging or continuous)

(ii)   process feed rates and composition

(iii)   fuel rates and composition

(iv)   normal operating and stack temperatures

(v)   normal operating and stack pressures

(vi)   pollution control equipment operation and efficiency

(vii)   physical dimensions and layout of the ducts or stacks

(viii)   volumetric stack gas flowrates

(ix)   stack gas composition

(x)   stack gas moisture content

(xi)   physical and chemical nature of the pollutants

(xii)   expected concentrations of particulate and gaseous pollutants.

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3.   Test Area Information

A personal inspection of the physical characteristics of the source shall be carried out by the source testing supervisor to evaluate potential test sections considering such factors as:

(i)   safety and shelter of team personnel

(ii)   location of flow disturbances

(iii)   accessibility of sampling site

(iv)   sampling platform space and scaffolding requirements

(v)   availability of electrical power, compressed air, water and steam

(vi)   sampling port locations

(vii)   circular versus rectangular flow cross-sections

(viii)   vertical versus horizontal ducting

(ix)   inside duct or stack diameter

E   LOCATION OF SAMPLING SITE

Preferably, a sampling site shall be located in a straight, vertical length of duct or stack at least eight duct or stack diameters downstream and at least two duct or stack diameters upstream from any flow disturbances such as bends, constrictions, expansions, fans, turning vanes, air cleaning equipment, visible flames, stack exits, etc. in order to reduce the number of sampling points to the required minimum. A round section of duct or stack shall be preferred over a rectangular section, all other variables being equal. For a rectangular duct, the largest dimension shall be used to represent the duct diameter.

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Downstream Flow →
Disturbance

2 Stack Diameters

Sampling Ports at 90° → 　O　　✳ Sampling Site

8 Stack Diameters

Upstream Flow →
Disturbance　　　　　　　　　　← Gas Flow

Sampling Port Perpendicular to
Centerline of Upstream Flow
Disturbance

Sampling Port Parallel
to Centerline of
Upstream Flow
Disturbance

Breaching Entering Base
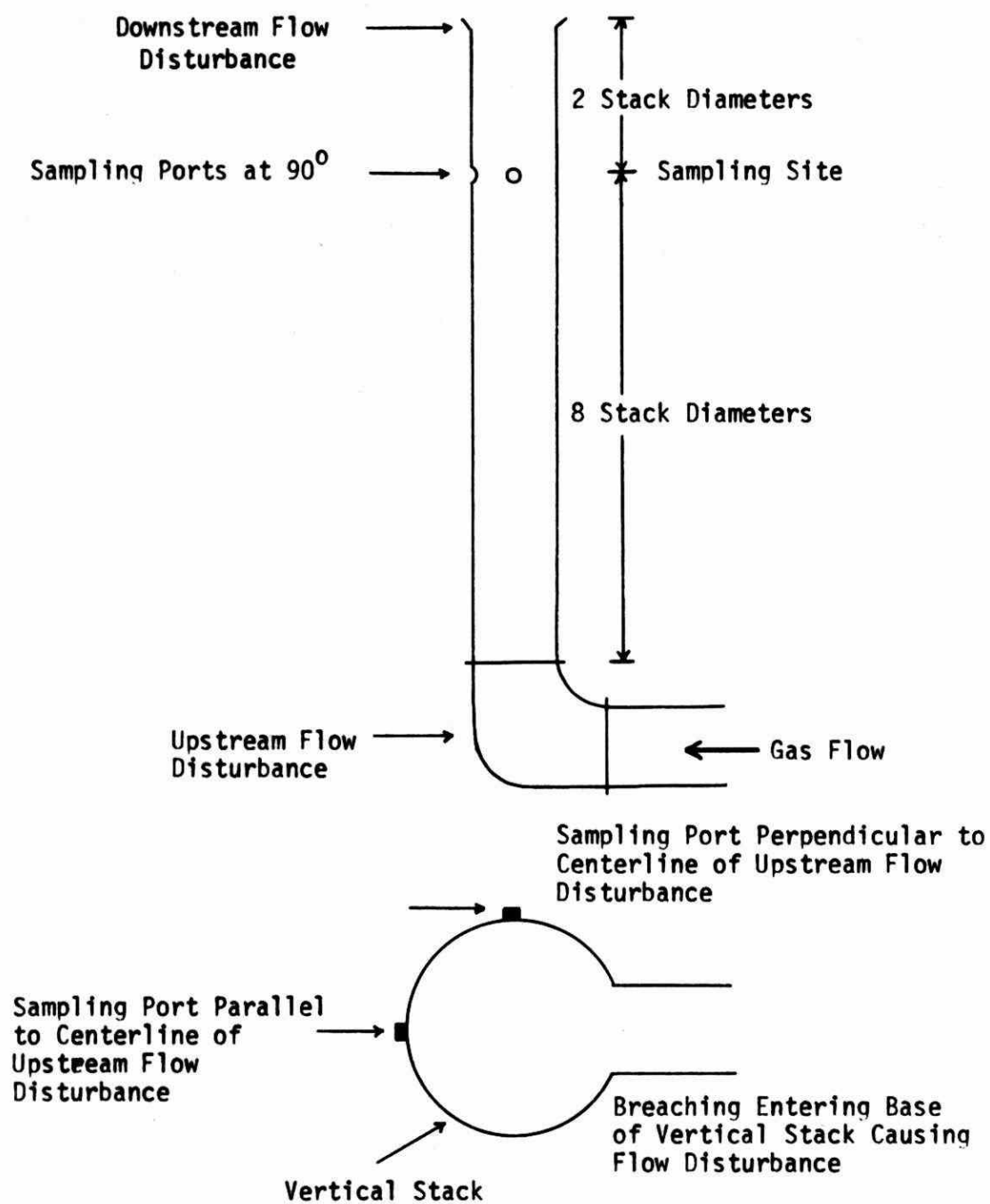of Vertical Stack Causing
Flow Disturbance

Vertical Stack

Figure I.　Location of Sampling Site

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When practical conditions dictate that a sampling site is to be located less than eight duct or stack diameters downstream from a flow disturbance, it shall be necessary to increase the number of sampling points above the required minimum. A sampling site shall not be located less than four duct or stack diameters downstream or less than two duct or stack diameters upstream of any flow disturbance without prior approval of the Air Management Branch.

At least two sampling ports, large enough to permit introduction of the sampling equipment (usually 4-inch diameter), shall be provided for each duct or stack to be tested. The sampling ports for circular ducts or stacks shall be located parallel and perpendicular to the centerline of the flow disturbance upstream from the sampling site. A means of sealing the unoccupied area of the sampling port without disturbing the sampling equipment shall be provided during all traverses to prevent in-leakage of ambient air. Figure 2 illustrates one example of a suitable fitting to seal the sampling port.

Figure 2. Pipe Plug for Sampling Port

Sampling ports for horizontal ducts should be installed on the side or on the top of the duct, not on the bottom. When possible, the sampling ports should be located on the side of the horizontal duct with the smallest dimension in order to minimize the numbers of times that the sampling apparatus must be moved from port to port.

F   NUMBER OF SAMPLING POINTS

The number of sampling points shall be determined by the diameter of the duct or stack whose emissions are to be sampled, the flow patterns encountered, and the location of the sampling site with respect to flow disturbances.

The minimum number of sampling points for circular ducts or stacks (generally vertical) is shown in Table 2 for various diameters. The minimum number of sampling points for rectangular ducts (generally horizontal) shall be determined by dividing the duct cross-sectional area into equal rectangular zones of 1 ft.^{2} and locating a sampling point at the center of each rectangular zone.

For rectangular and circular ducts or stacks in which the sampling site is to be located less than eight duct or stack diameters downstream from a flow disturbance, the required number of sampling points shall be determined from Table 3.

G   LOCATION OF SAMPLING POINTS

Unless otherwise specified or approved by the Air Management Branch, sampling points will be located at the centroid of equal areas in circular ducts or stacks. Use Table 1 to locate the sampling points in

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circular ducts or stacks. In rectangular ducts they will be located at the center of equal rectangular zones as shown in Figure 3.

H   PRELIMINARY PROCEDURES

After a sampling site has been selected using the criteria as specified by "Test Area Information", preliminary traverses of the duct or stack using the number of sampling points as required by Table 2 and Table 3, shall be conducted at the sampling site to determine the stack gas velocity and temperature profiles, the absolute stack gas pressure, the stack gas composition and hence molecular weight, the stack gas moisture content, the volumetric stack gas flowrate, all in accordance with the specified test methods. In addition, an estimate of the physical and chemical nature of the pollutants should be made. All the data collected during the preliminary traverses shall be recorded and reported.

On the basis of results obtained from the preliminary traverses, final decisions shall be reached with respect to the following:

1.   Choice of Sampling Train Components

The final choice of sampling train components depends on the conditions encountered in the duct or stack during the preliminary traverses. The physical and chemical nature of the pollutants, the concentration of the pollutants, the subsequent analysis required as well as the temperature, corrosiveness, and moisture content of the stack gas will largely determine the components to be used in the sampling train for the source sampling tests.

2.   Choice of Isokinetic Sampling Nozzles

The correct size of nozzle required for isokinetic sampling

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(Percent of stack diameter from inside wall to traverse point)

Traverse point number on a diameter	Number of traverse points on a diameter											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.3	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.7	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.5	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.5	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.3	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.5	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.5	36.6	28.3	23.6	20.4	18.0	16.1
8				96.7	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.1	23.0
10					97.5	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.9	67.7
15								95.1	89.1	83.5	78.2	72.8
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

Table 1. Distances to Sampling
Points in Circular
Ducts or Stacks

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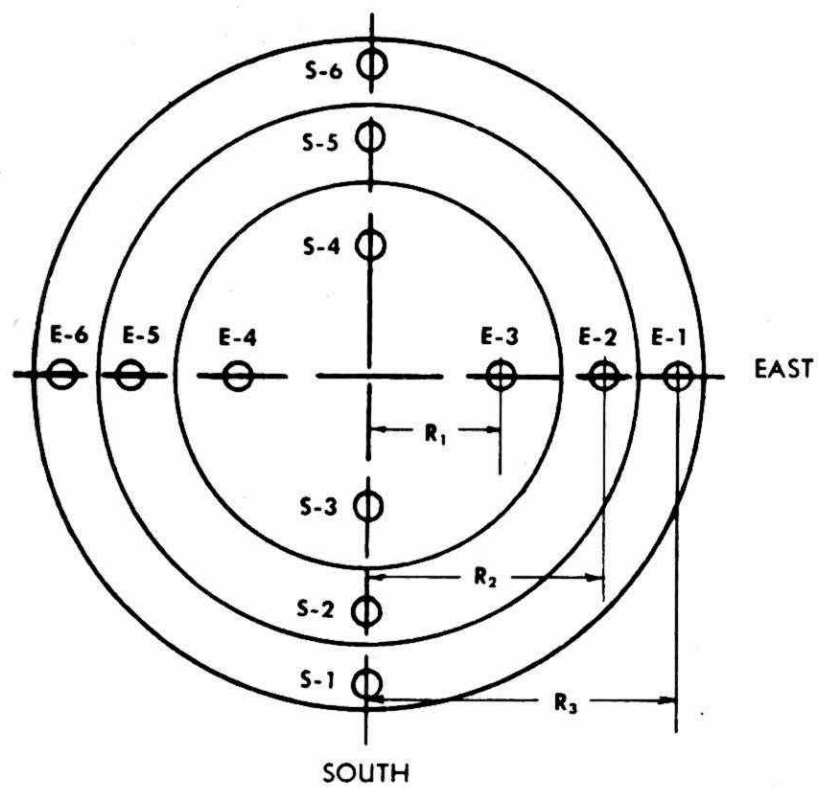
Figure 3. Location of Sampling Points

Duct Diameter, ft.	Required Minimum Number of Sampling Points Per Traverse
Less than 2	4
2 ≤ 4	8
4 ≤ 8	12
8 ≤ 14	16
14 ≤ 20	20
Greater than 20	Refer to Air Management Branch for approval prior to testing.

Table 2. Minimum Number of Sampling Points
Per Traverse for Circular Ducts or
Stacks for a Sampling Site Located
at Least Eight Diameters Downstream
of a Flow Disturbance.

Number of Duct Diamaters From Upstream Flow Disturbance	Required Number of Sampling Points Per Traverse
$<$ 8 diameters	*Minimum number of sampling points as in Table 2
6 - 8 diameters	*1.5 times minimum number of sampling points as in Table 2
4 - 6 diameters	2.0 times minimum number of sampling points as in Table 2
$<$ 4 diameters	Refer to Air Management Branch for approval prior to testing

* For unusual velocity distributions, if the ratio of the maximum velocity to the minimum velocity measured at any two points at sampling site (excluding the boundary layer near the stack wall) exceeds a 2:1 ratio, it shall be necessary to use two times the minimum number of sampling points as in Table 2.

Table 3. Number of Sampling Points Per Traverse for Circular Ducts or Stacks for a Sampling Site Less Than Eight Diameters Downstream of a Flow Disturbance

shall be selected using the data collected during the preliminary traverses. The proper choice of sampling nozzle size will eliminate unnecessary changes of the nozzle during subsequent particulate matter or aerosol mist traverses. The minimum nozzle size shall be ½" I.D.

3. Isokinetic Sampling Rate

An isokinetic sampling flowrate shall be calculated for each point to be sampled for particulate matter or aerosol mist. Nomographs and tables shall be prepared from data collected during the preliminary traverses to calculate the required isokinetic sampling flowrates during subsequent source sampling tests. A calibrated rate meter shall be used to indicate the instantaneous isokinetic sampling rate during source sampling tests. The rate meter shall be sensitive enough to indicate the instantaneous isokinetic sampling rate required for existing stack gas conditions. Determining the sampling flowrate by timing the sweep hand on the dry gas meter as a measured volume of gas passes through the meter requires far too much time and is an unacceptable method of sampling flowrate calculation. When sampling for gaseous pollutants, isokinetic sampling will not be required, but proportional sampling using a traversing technique may sometimes be required.

4. Approach to Isokinetic Sampling

Isokinetic sampling conditions shall be maintained when sampling for particulate matter or aerosol mist. Isokinetic sampling means the velocity of the stack gas entering the sampling nozzle equals the velocity of the undisturbed gas stream at the sampling point. To satisfy the requirement of isokinetic sampling, a calibrated S-type pitot tube with an attached, calibrated thermo couple shall be permanently fixed adjacent to the sampling probe

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to continuously measure the stack gas velocity and temperature at the same time that a sample of particulate matter or aerosol mist is continuously withdrawn from each sampling point in the duct or stack. Should changes in the stack conditions occur and/or a change in the sampling flowrate through the sampling train due to a buildup of particulate matter or aerosol mist on the filter, then a new isokinetic sampling flowrate shall be calculated using the prepared nomographs and tables and immediately established.

All instruments in the sampling train shall be read and the readings recorded at two minute intervals during the sampling period at each sampling point. In addition, all instrument readings shall be read and recorded each time the sampling flowrate is adjusted or a component in the sampling train is replaced.

5. Number of Sampling Points

The number of sampling points required shall be determined using Tables 2 and 3. For unusual velocity distributions, if the ratio of the maximum velocity to the minimum velocity measured at any two points at the sampling site (excluding the boundary layer near the stack wall) exceeds a 2:1 ratio, it shall be necessary to use two times the minimum number of sampling points as in Table 2.

6. Sampling Time Per Point

The sampling time per point shall be determined by the concentration of particulate matter or aerosol mist in the stack gas and the process production rates and operating conditions for the source to be tested. A sampling time per point of at least ten minutes shall be used for stack

gases with a low concentration of particulate matter or aerosol mist
(gases which have passed through medium and high energy wet scrubbers,
baghouses and electrostatic precipitators, etc.) and at least five minutes
per point for stack gases with a high concentration of particulate matter
or aerosol mist (gases which are emitted directly to atmosphere or which
have passed through mechanical collectors or low energy wet scrubbers).

For processes whose emissions vary significantly with time,
an incremental sampling technique may be specified by the Air Management
Branch requiring a considerably longer sampling time per point (>10 minutes).
The sampling time per point would be dependent on the nature of the time-
wise variations in emissions and would be different for each process. Situa-
tions such as the above shall be referred to the Air Management Branch for
resolution.

Each point in the duct or stack shall be sampled for the same
period of time.

7.   Duration of Source Sampling Test

Particulate matter or aerosol mist sampling tests shall be as
long as possible with two to six hours being considered a usual test period.
The minimum volume of stack gas sampled during each sampling test shall be
at least 60 ft.^{3} on a dry basis at reference conditions (70^0F, 29.92 inches
Hg).

For cyclic and batch processes with a long cycle (several hours)
between changes or upsets in plant operation, source sampling tests shall
cover one or more process cycles.

If significant peaks of emission occur during a process cycle
(charging operations, etc.), it shall be necessary to divide the cycle into

a number of intervals. Separate sampling tests shall be conducted in each interval as well as tests over the entire duration of the cycle.

If a process cycle is of short duration, it shall be necessary to conduct a greater number of tests than would normally be required (three).

Should a situation arise in which the total time available to sample the process emissions is less than the calculated total sampling time (number of sampling points times sampling time per point), it shall be referred to the Air Management Branch for resolution.

8. Mode of Traversing

    a. Cumulative Sampling

    The cumulative method of sampling consists of collecting samples of particulate matter or aerosol mist from the required number of sampling points for a specified period of time until the traverse is complete. All sampling points should be sampled in order starting with the point closest to the far wall of the stack. When the first point has been sampled, the probe shall be quickly moved to the next point and the sampling flowrate adjusted to isokinetic conditions. When the entire traverse has been completed, the sampling probe shall be carefully removed from the stack to prevent any loss of particulate matter or aerosol mist and the vacuum pump shall be turned off. The same procedure shall be used for the second traverse which shall commence after completion of the first traverse. At least two cumulative stack traverses at 90^0 to each other shall be required for each stack test.

    b. Incremental Sampling

    Incremental sampling involves a separate measurment of the particulate matter or aerosol mist concentration at each sampling point.

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The incremental method is extremely time consuming since the entire sampling train must be cleaned out before proceeding to the next sampling point. An incremental sampling technique may be specified by the Air Management Branch if skewed distributions exist in a duct or stack at the sampling site or if significant time-wise variations in emissions from a process are suspected.

I   TEST METHODS

1.   Volumetric Stack Gas Flowrate

The volumetric stack gas flowrate shall be determined from measurements of the stack gas velocity and temperature, the absolute stack gas pressure, the stack gas composition and hence molecular weight and stack gas moisture content made during the traverses.

a. Instrumentation

1) S-Type Pitot Tube

A stainless steel, (or Inconel) calibrated S-Type pitot tube with an attached, calibrated, sheathed thermocouple shall be used to measure the stack gas velocity head and temperature at each point in the duct or stack, especially when the stack gases are nearly saturated with condensables or contain a high concentration of particulate matter or aerosol mist. An inclined manometer, attached to the pitot tube, shall be used to indicate the stack gas velocity head to within 0.005 inches of H_2O. The S-type pitot tube should be calibrated periodically or when the tips have been damaged or the tubes have been bent. Figure 4 illustrates the S-type pitot tube.
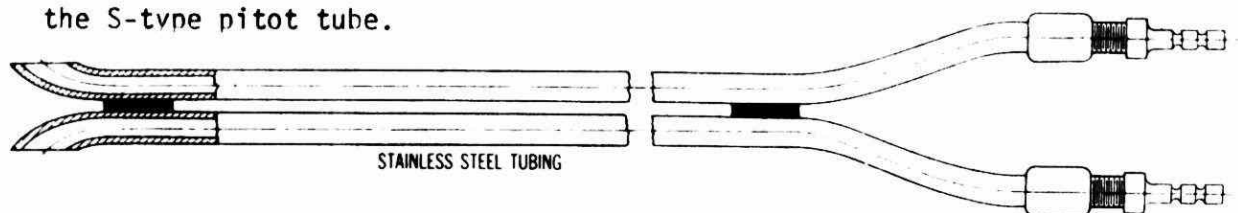

STAINLESS STEEL TUBING

FIGURE 4.   S-Type Pitot Tube

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2) Standard Pitot Tube

A stainless steel, pitot tube (ellipsoidal or hemispherical nose type) with an attached, calibrated, sheathed thermocouple may also be used to measure the stack gas velocity head and temperature at each point when plugging of the tube openings is not a problem.

Situations in which the stack gas velocity head is too small to be measured with a pitot tube and inclined manometer shall be referred to the Air Management Branch for resolution.

3) Barometer

A barometer shall be used to measure the atmosphere pressure to within 0.1 inches Hg at the sampling site.

4) Thermocouple

Since a simultaneous measurement of the stack velocity head and temperature is required at each point in the duct or stack, a calibrated, sheathed thermocouple attached to the S-type pitot tube shall be used to measure the stack gas temperature to within 1.5% of the minimum absolute stack gas temperature. Appropriate shielding and aspiration shall be provided for the thermocouple when gas temperatures are greater than 700°F. The type of thermocouple to be used depends on the temperature and corrosiveness of the stack gases. A suitable device shall be used to directly indicate the stack gas temperature in ^{o}F as measured by the thermocouple.

b. Procedure

Carefully measure the inside diameter of the duct or stack at the sampling site taking into account the stack lining or deposits which may have formed on the stack walls. If portions of the stack lining or deposits

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have broken away thus creating a variable inside diameter, a new sampling site should be selected. Based on the inside diameter and the location of the sampling site with respect to flow disturbances, determine the number of sampling points from Table 2 and 3. Measure the stack static pressure by connecting one leg of the S-type pitot tube to one side of a U-tube water gauge manometer with the other side open to the atmosphere. The S-type pitot tube should be turned sideways in the gas stream. Measure the atmospheric pressure at the sampling site with a barometer. Determine the absolute stack gas pressure using equation (1).

$$P_s = P_{bar} + (\frac{P_{static}}{13.6}) \hspace{2cm} (1)$$

where

P_s = Absolute stack gas pressure, inches Hg

P_{bar} = Atmospheric pressure at the sampling site, inches Hg

P_{static} = Stack gas static pressure, inches H_2O

13.6   = Conversion factor, $\frac{inches\ H_2O}{inches\ Hg}$

Determine the stack gas composition, molecular weight and moisture content using the specified test methods. Attach the inclined manometer to the S-type pitot tube making sure the manometer is properly levelled, zeroed and all connections are leak free. The zero reading of the manometer shall be checked before and after each set of readings. Screw the pipe plug tightly into the pipe coupling to prevent any in-leakage of ambient air. Mark off the distances

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to each sampling point on the pitot tube taking into account the stack lining (if any) and the length of pipe coupling welded to the sampling port. Carefully insert the pitot tube into the duct or stack through the hole drilled in the pipe plug. Position the pitot tube at the first sampling point so that it is properly aligned with the stack gas streamlines. Secure the pitot tube so that it does not move in the gas streamlines. Allow sufficient time for the pitot tube-thermocouple assembly to measure the stack gas velocity head and temperature at each sampling point. Record the stack gas velocity head and temperature and the other pertinent information as required in Figure 5. Use equation (2) to calculate the stack gas velocity at each point.

$$U_s = K_p \, C_v \, \left(\frac{T_s \, \Delta p}{P_s \, M_s} \right)^{\frac{1}{2}} \qquad (2)$$

where

U_s = Stack gas velocity, ft/sec.

K_p = Constant, $85.48 \frac{ft.}{sec.} \left[\frac{lb}{lb. \, mole - {}^oR} \right]^{\frac{1}{2}}$

C_v = S-type pitot tube coefficient, dimensionless.

T_s = Absolute stack gas temperature, ${}^oR$

Δp = Stack gas velocity head, inches H_2O

P_s = Absolute stack gas pressure (see equation 1), inches Hg

M_s = Molecular weight of stack gas on wet basis (see equation 6),

   $\frac{lb}{lb. \, mole}$

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Plant _____

Location _____

Test _____

Date _____

Time Started _____

Time Completed _____

Stack Diameter, inches _____

Barometric Pressure, inches Hg _____

S-Type Pitot Tube Coefficient, dimensionless _____

Operators _____

Traverse Point	Stack Gas Velocity Head Δp (inches H_2O)	Stack Gas Temperature ($^{\circ}F$)
		Average

Figure 5. Velocity Traverse Data Sheet

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B_{wo} = Proportion by volume of water vapor in the stack gas (see equation 9), dimensionless

The average stack gas velocity shall be determined by averaging the individual stack gas velocities at each point in the duct or stack.

Use equation (3) to calculate the volumetric stack gas flowrate in the duct or stack.

$$Q_s = 3600 \ (U_s)_{avg} \ A_s \ (1-B_{wo})\left(\frac{T_{ref}}{(T_s)_{avg}}\right)\left(\frac{P_s}{P_{ref}}\right) \qquad (3)$$

where

Q_s = Volumetric stack gas flowrate on dry basis at reference conditions, $\frac{ft.^3}{hr.}$

$(U_s)_{avg}$ = Average stack gas velocity (see equation 2), $\frac{ft.}{sec.}$

A_s = Cross-sectional area of duct or stack, $ft.^2$

B_{wo} = Proportion by volume of water vapor in stack gas (see equation 9), dimensionless

T_{ref} = Absolute temperature at reference conditions, $530^{\circ}R$

$(T_s)_{avg}$ = Average absolute stack gas temperature, $^{\circ}R$

P_s = Absolute stack gas pressure, inches Hg

P_{ref} = Absolute pressure at reference conditions, 29.92 inches Hg

3600 = Conversion factor, $\frac{sec.}{hr.}$

2.   Stack Gas Composition and Molecular Weight

The important gaseous constituents of the stack gases which shall

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be considered when determining the stack gas composition and molecular weight are carbon dioxide (CO_2), oxygen (O_2), carbon monoxide (CO), and nitrogen (N_2). An Orsat analyzer should be used to measure the percent by volume of CO_2, O_2 and CO present in the stack gases. If sulphur dioxide (SO_2) or other gaseous constituents are present in the stack gases in significant percentages, they too shall be taken into account when calculating the stack gas composition and molecular weight.

At least three grab samples of the stack gases shall be withdrawn from the duct or stack and analyzed for CO_2, O_2, and CO during the preliminary traverses prior to the actual sampling tests. In addition, measurements of the stack gas composition and molecular weight shall be made on each successive day that sampling tests are conducted.

a. Instrumentation

1) Sampling Probe

The sampling probe is made of Pyrex glass (or stainless steel) with an inside diameter of at least 5 to 6 mm. The end of the probe exposed to the stack gases is packed with quartz or Pyrex wool to remove particulate matter.

2) Pump

A one-way squeeze bulb is used to withdraw a sample of the stack gases to the gas analyzer.

3) Orsat Analyzer

An Orsat analyzer is used to measure the percent by volume of CO_2, O_2, and CO present in the grab samples of the stack gases. Other analyzers such as portable gas chromatographs, NDIR analyzers, may also be used in place

of the Orsat Analyzer.

b. Sampling Procedure

Connect the squeeze bulb to the sampling probe. Screw the pipe plug tightly into the pipe coupling to prevent any in-leakage of ambient air. Insert the sampling probe to the center of the stack through the hole drilled in the pipe plug and secure the probe. Purge the sampling probe with samples of the stack gases. Connect the Orsat analyzer to the squeeze bulb and withdraw a sample of the stack gases to fill the gas burette of the analyzer. The sample of stack gases is alternatively scrubbed with 3 separate chemical solutions. The volume of gas remaining after each successive scrubbing is read directly in percent from the burette. Determine the percent by volume of CO_2 first by absorption in a solution of KOH; determine the percent by volume of O_2 by absorption in a solution of pyrogallic acid with the difference in the O_2 reading and CO_2 reading being the percent by volume O_2. CO is measured last by absorption in a solution containing metallic copper and ammoniacal cuprous chloride. The difference between the O_2 reading and the CO reading is the percent by volume of CO. The order of removal must be CO_2, O_2 and CO since each of the succeeding solutions will remove any portion of the O_2 and CO which is allowed to remain in the gas sample. Record data as required by Figure 6.

Plant _____

Location _____

Test _____

Date _____

Operators _____

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Time	Orsat Test Number	% CO_2	% O_2	% CO	% N_2
	Average				

Figure 6. Stack Gas Composition Data Sheet

Use equation (4) to calculate the stack gas composition.

$$(\% \ N_2) \ avg = 100 - \left[(\% \ CO_2) \ avg + (\% \ O_2) \ avg + (\% \ CO)_{avg} \right] \quad (4)$$

where

$(\% \ N_2) \ avg$ = Average percent by volume of N_2 by Orsat analysis, %

$(\% \ CO_2) \ avg$ = Average percent by volume of CO_2 by Orsat analysis, %

$(\% \ O_2) \ avg$ = Average percent by volume of O_2 by Orsat analysis, %

$(\% \ CO)_{avg}$ = Average percent by volume of CO by Orsat analysis, %

Use equation (5) to calculate the stack gas molecular weight on a dry basis.

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$$M_d = 0.44 \ (\% \ CO_2)_{avg} + 0.32 \ (\% \ O_2)_{avg} +$$

$$0.28 \left[(\% \ N_2)_{avg} + (\% \ CO)_{avg} \right] \ (5)$$

where

M_d = Molecular weight of stack gas on dry basis, $\dfrac{lb}{lb. \ mole}$

$(\% \ CO_2)_{avg}$ = Average percent by volume of CO_2 in stack gases on dry basis (see equation 4), %

$(\% \ O_2)$ = Average percent by volume of O_2 in stack gases on dry basis (see equation 4), %

$(\% \ CO)_{avg}$ = Average percent by volume of CO in stack gases on dry basis (see equation 4), %

$(\% \ N_2)_{avg}$ = Average percent by volume of N_2 in stack gases on dry basis (see equation 4), %

0.44 = Molecular weight of CO_2 divided by 100

0.32 = Molecular weight of O_2 divided by 100

0.28 = Molecular weight of CO and N_2 divided by 100

Use equation (6) to calculate the molecular weight of the stack gas on a wet basis.

$$M_s = M_d \ (1 - B_{wo}) + 18 \ B_{wo} \qquad (6)$$

where

M_s = Molecular weight of stack gas on wet basis, $\dfrac{lb}{lb. \ mole}$

M_d = Molecular weight of stack gas on dry basis, $\dfrac{lb}{lb. \ mole}$

B_{wo} = Proportion by volume of water vapor in stack gas, dimensionless

18 = Molecular weight of water, $\dfrac{lb}{lb.\ mole}$

3. Stack Gas Moisture Content

The recommended method shall consist of passing a measured volume of stack gas at a constant sampling rate through a condenser system immersed in an ice bath and measuring the volume of water vapor condensed exclusive of other condensible material.

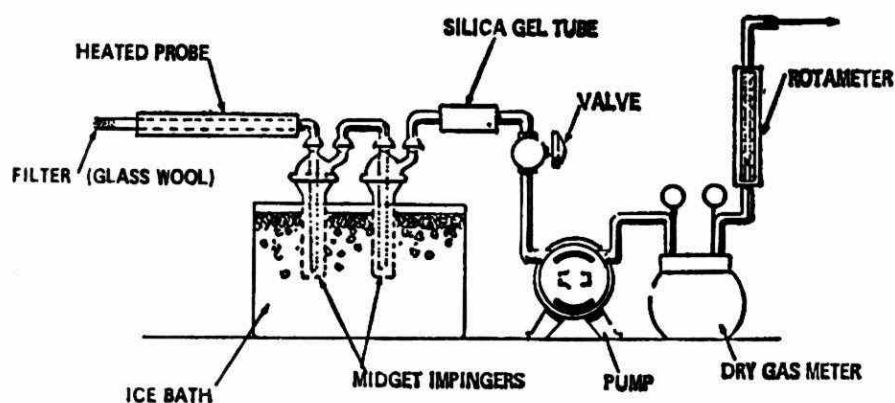Figure 7 illustrates the moisture sampling train.

Figure 7. Stack Gas Moisture Sampling Train

If liquid droplets are present in the stack gas, it shall be necessary to assume the stack gas to be saturated; the average stack gas temperature from the velocity traverse data sheet (Figure 5) and a psychometric chart shall be used to determine the stack gas moisture content.

If the stack gas temperature is less than 212°F and the stack gas velocity is greater than 15 ft./sec., wet and dry bulb temperature measure-

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ments and a psychometric chart may be used to determine the stack gas moisture content. The sock on the wet bulb thermometer shall be kept wet at all times. The wet bulb temperature shall be read when it has reached its equilibrium value. This technique shall not be used in acid gas streams.

The measurement of the stack gas moisture content shall be made during the preliminary traverses prior to the actual sampling tests. In addition, measurements of the stack gas moisture content shall be made on each successive day that sampling tests are carried out (see equation 12).

a. Instrumentation

1) Sampling Probe

The sampling probe is made of Pyrex glass (or stainless steel) with an inside diameter of at least 5 to 6 mm. The probe is equipped with an electrical heating system to prevent condensation of moisture in the probe. The end of the probe exposed to the stack gases is packed with quartz or Pyrex wool to remove particulate matter.

2) Impinger Train

The impinger train consists of two midget impingers immersed in an ice bath to condense any moisture present in the gas sample and to keep the temperature of the gases leaving the last midget impinger at 70°F or less during the test period. Should the temperature of the gases leaving the condenser differ from 70°F, the value of B_{wm} (see equation 9) will change and shall be corrected.

3) Drying Tube

A drying tube (optional) packed with 6 to 16 mesh, indicating type, silica gel.

4) Needle Valve

A needle valve is used to adjust the sampling flowrate through the

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sampling train.

5) Vacuum Pump

A leak free vacuum pump is used to continuously draw a sample of the stack gases through the sampling train.

6) Dry Gas Meter

A calibrated dry gas meter is used to measure and indicate the total volume of gas sampled. The dry gas meter is equipped with suitable temperature and pressure measuring devices to measure the meter inlet and outlet gas temperature and the gas pressure.

7) Rotameter

A calibrated rotameter (range 0 - 0.1 cfm) is used to measure and indicate the instantaneous sampling flowrate through the sampling train.

b. Sampling Procedure

Measure the atmospheric pressure to within 0.1 inches Hg at the sampling site using a barometer. Assemble the moisture sampling train as shown in Figure 7. Leak test the sampling train by plugging the inlet to the first midget impinger and drawing a vacuum. Correct any leaks in the train. Screw the pipe plug into the pipe coupling to prevent any in-leakage of ambient air. Insert the heated sampling probe to the center of the stack through the hole drilled in the pipe plug and secure the probe. Sample at a constant rate of 0.075 cfm until a measurable amount of water vapor has been condensed in order to make a reliable estimate of the stack gas moisture content. Record the data required in Figure 8 as the test progresses.

Measure the volume increase in the midget impingers to the nearest 0.5 ml.

Use equation (7) to calculate the volume of water vapor collected.

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$$V_{wc} = \frac{(V_f - V_i) \, \rho_{H_2O} \, RT_{ref}}{453.59 \, P_{ref} \, M_{H_2O}}$$

$$= 0.0474 \, \frac{ft.^3}{ml} \, (V_f - V_i) \qquad (7)$$

where

V_{wc} = Volume of water vapor collected at reference conditions, ft.^{3}

V_f = Final volume of impinger contents, ml.

V_i = Initial volume of impinger contents, ml.

R = Ideal gas constant, $21.83 \, \frac{\text{inches Hg - ft.}^3}{\text{lb.mole -}^\circ R}$

ρ_{H_2O} = Density of water, $1 \, \frac{gm.}{ml.}$

T_{ref} = Absolute temperature at reference conditions, $530^\circ R$

P_{ref} = Absolute pressure at standard conditions, 29.92 inches Hg

M_{H_2O} = Molecular weight of water, $18 \, \frac{lb}{lb. \, mole}$

453.59 = Conversion factor, $\frac{gm}{lb.}$

Plant _____

Location _____

Test _____

Date _____

Barometric Pressure, inches Hg _____

Volume of Moisture Condensed, ml. _____

Operators _____

Time	Meter Volume (ft.^{3})	Meter Temperature (^{o}F)		Meter Pressure (inches Hg.)	Rotameter Reading (ft.^{3}/min)	Last Impinger Temperature (^{o}F)
		Inlet	Outlet			

Figure 8. Stack Gas Moisture Data Sheet

Use equation (8) to calculate the volume of gas sampled at reference conditions.

$$V_{mc} = V_m \left(\frac{P_m}{P_{ref}}\right) \left(\frac{T_{ref}}{T_m}\right)$$

$$= 17.71 \frac{^oR}{inches\ Hg} \left(\frac{V_m P_m}{Tm}\right) \qquad (8)$$

where

V_{mc} = Dry gas volume through dry gas meter at reference conditions, ft.^{3}

V_m = Dry gas volume measured by dry gas meter, ft.^{3}

P_m = Absolute pressure at the dry gas meter, inches Hg.

P_{ref} = Absolute pressure at reference conditions, 29.92 inches Hg.

T_m = Absolute temperature at dry gas meter, ^{o}R

T_{ref} = Absolute temperature at reference conditions, 530°R

Use equation (9) to calculate the stack gas moisture content.

$$B_{wo} = \frac{V_{wc}}{V_{wc} + V_{mc}} + B_{wm}$$

$$= \frac{V_{wc}}{V_{wc} + V_{mc}} + 0.025 \qquad (9)$$

where

B_{wo} = Proportion by volume of water vapor in the gas stream, dimensionless

V_{wc} = Volume of water vapor collected at reference conditions, ft.^{3}

(see equation 7)

V_{mc} = Dry gas volume through dry gas meter at reference conditions, ft.^{3}

(see equation 8)

B_{wm} = Approximate volumetric proportion of water vapor in the gas stream leaving the last impinger, 0.025

4.   Particulate Matter

Particulate matter is withdrawn isokinetically from a specified number of sampling points in a stack or duct and its weight is determined gravimetrically after removal of uncombined water.

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a. Instrumentation

The particulate matter sampling train is illustrated in Figure 9. Commercial models of this sampling train are currently available.

1) Sampling Nozzle

The recommended type of sampling nozzle is the buttonhook nozzle. The sampling nozzle shall have a leading edge that is thin, well-rounded and sharp. The nozzle edge shall be tapered on the outside and shall have straight internal walls. Null balance nozzles shall not be used.

Depending on the temperature and corrosive constituents of the stack gases to be sampled, the sampling nozzles shall be made of stainless steel, Pyrex glass, Vycor, borosilicate or quartz.

A variety of sampling nozzle sizes (minimum inside diameter is ¼") shall be required to provide isokinetic sampling over the range of stack gas velocities and particulate matter size distributions to be encountered in the duct or stack. The nozzle shall be large enough to satisfy the minimum volume of gas to be sampled (60 ft.^{3} on a dry basis at reference conditions).

During a particulate matter traverse, the sampling nozzle shall point directly into the approaching stack gases. Misalignment of the sampling nozzle with the approaching gas streamlines can result in significant errors in sampling.

2) Sampling Probe

The sampling probe shall be straight, with no bends, for easy insertion and removal from the duct or stack. The sampling probe should be long enough to traverse the duct or stack to be sampled. Fixed adjacent to
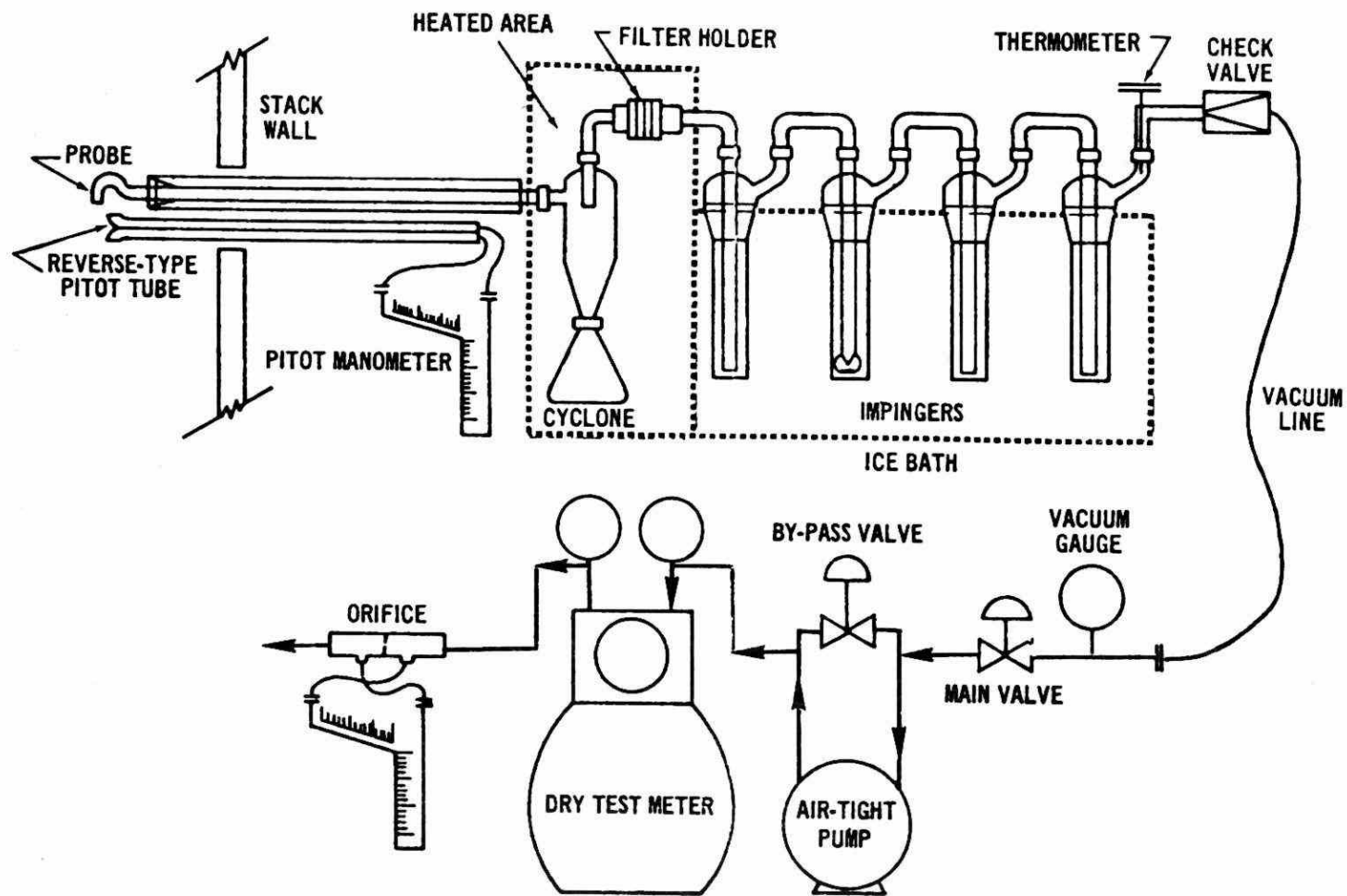
Figure 9. Particulate Matter Sampling Train

the probe shall be a calibrated S-type pitot tube with an attached cali-
brated, sheathed thermocouple. The center-to-center distance between the
sampling nozzle (attached to the probe) and the lower leg of the S-type
pitot tube shall be 3/4". The tip of the sampling nozzle shall extend
2 nozzle diameters below the tip of the S-type pitot tube's lower leg.

The sampling probe shall consist of Pyrex glass tubing (Vycor
and quartz tubing for temperatures above $500^\circ F$) encased in stainless steel
tubing. Where length or strength limitations preclude the use of a glass
liner, the sampling probe shall be made of stainless steel. The glass tubing
shall be electrically heated by a resistance element capable of maintaining
a minimum gas temperature of $250^\circ F$ (at the exit end) or over the gas dewpoint
if the dewpoint exceeds $250^\circ F$. The temperature at the exit end of the probe
shall be recorded as required in Figure 10.

Provision shall be made for special, stainless steel water
cooled sampling probes where hot stack gases may damage or distort the nozzle-
probe assembly. The sampling probes shall not be cooled to the extent that
condensation occurs in the probe.

A suitable sampling probe support system shall be used to pre-
vent probe movement or misalignment in the stack gases. A pipe plug, drilled
out to provide entry for the sampling probe-pitot tube apparatus, shall be
used to seal the sampling port and prevent in-leakage of ambient air. The
sampling probe-pitot tube apparatus shall not be hand held during the traverses.

3) Miniature Cyclone

A miniature cyclone made of Pyrex glass should follow the sam-
pling probe and precede the filter in the sampling train if there is a signi-
ficant amount of large particles in the stack gases which may cause premature

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build-up of particulate matter on the filter medium.

The miniature cyclone shall be electrically heated by a system capable of maintaining a minimum gas temperature of $225^O F$ or over the gas dewpoint if the dewpoint exceeds $225^O F$.

Should the cyclone collection flask become filled with particulate matter during a traverse, sampling shall cease just long enough to remove and seal the collection flask, and replace it with another pre-weighed collection flask. The collection flask shall be heated before sampling is resumed. All the data as required in Figure 10 shall be recorded when the collection flask is removed and replaced.

4) Filter Holder and Filter

The choice of filter medium depends on the type, size and amount of particulate matter, the temperature and corrosive constituents in the stack gases and the subsequent analysis required. The filter holder and filter shall follow the cyclone if used; otherwise, it shall follow the sampling probe and precede the impingers in the sampling train.

The filter holder shall be made of Pyrex glass and shall be electrically heated by a system capable of maintaining a minimum gas temperature of $225^O F$ or over the gas dewpoint if the dewpoint exceeds $225^O F$. The temperature of the filter holder shall be recorded as required in Figure 10.

The filter shall be at least three inches in diameter and shall be supported in the glass filter holder by a silicone rubber gasket and a porous, fritted disc. The recommended type of filter shall be flash fired glass fibre (organic binder removed) capable of retaining particles as small as 0.3 microns. Other types of filters (membranes for particle size analysis,

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teflon for particulate matter chemical analysis and fluorides) of equivalent particle retention efficiency may be specified by the Air Management Branch depending on the type of particulate matter analysis required. Prior to the actual test, the glass fibre filters shall be numbered and desiccated at $70^{\circ}F$ for 24 hours. The filters shall be weighed to the nearest 0.5 mg. in an atmosphere with less than 50% humidity and shall be installed in sealed, clean filter holders to avoid contamination during transportation to the sampling site.

Should the filter become plugged with particulate matter during a traverse or, should the pressure drop across the filter become excessive and prevent leak-free operation of the vacuum pump, replace it with another filter holder containing a numbered, desiccated, pre-weighed filter. The plugged filter shall not be removed from the filter holder at the sampling site. The clean filter holder and filter shall be heated before sampling is resumed. All the data as required in Figure 10 shall be recorded when the filter holder and filter are removed and replaced.

At the conclusion of a day's testing, the used filters can be removed from their filter holders, placed in numbered and weighed petri dishes and sealed for transportation back to the laboratory. The filter holders should be cleaned in accordance with Section 4c "Sample Recovery". Additional numbered, desiccated, pre-weighed filters brought to the plant site is numbered and weighed petri dishes should be installed in the clean filter holders for the next day's testing. All these operations shall take place in a clean room and not at the sampling site.

Should the filter be burned, torn or chemically attacked during a

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Plant _____

Location _____

Test _____

Date _____

Ambient Temperature, °F _____

Barometric Pressure, inches Hg. _____

Moisture Content, % _____

Nozzle Diameter, inches _____

Probe Length, ft. _____

Probe Temperature, °F _____

Filter Holder Temperature, °F _____

Meter△H @ _____

C Factor (or K factor) _____

Operators _____

Traverse Point	Time	Stack Gas Temperature (°F)	Velocity Head (inches H₂0)	Orifice Pressure Drop (inches H₂0)	Gas Meter Volume (ft.³)	Gas Meter Temperature (°F)		Temperature of Gas Leaving Last Impinger (°F)	Pump Intake Vacuum (inches Hg.)
						Inlet	Outlet		
Total				Average	Total	Avg.	Avg.		
						Average			

Figure 10. Particulate Matter Data Sheet

traverse, sampling shall cease and the traverse shall be rejected. The entire sampling train shall be cleaned out, the filter holder and filter replaced and the sampling test shall be repeated from the beginning.

Measurements of particle size and particle size distribution by cascade impactors or other devices shall be referred to the Air Management Branch prior to the actual sampling tests.

5) Impinger Train

The impinger train shall follow directly after the filter and shall be immersed in an ice bath to continuously cool the sampled gases and condense any water vapor present in the gases. The exit of the last impinger in the train shall contain a temperature measuring device to measure and indicate the temperature of the gases leaving the impinger train (which should be 70°F or less).

The impinger train shall consist of four Greenburg-Smith impingers connected in series. The first, third and fourth impingers shall be modified by replacing the tip and impaction plate of the standard design with a ½" I.D. glass tube extending to ½" from the bottom of the flask. The second impinger shall have the standard tip and impaction plate. The first two impingers shall contain 100 ml. each of deionized or distilled water and the third impinger shall be left dry. The Branch may specify the use of other impinger collection media than distilled water depending on the type of particulate matter being sampled (e.g. nitric acid when sampling lead emissions). The fourth impinger shall contain at least 200 gm. of indicating type silica gel (6-16 mesh) which has been dried for 2 hours at 350°F. The silica gel shall not be allowed to change color completely or become saturated with moisture.

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An additional, weighed and dried amount of silica gel should be added to the fourth impinger or the fourth impinger should be replaced with another impinger containing fresh silica gel.

6) Vacuum Pump

A leak-free vacuum pump shall be used to continuously withdraw samples of the stack gases through the sampling train. The vacuum pump shall be connected to the exit of the impinger train by means of a vacuum line which contains a vacuum gauge to measure the pump intake vacuum to within 0.1 inches Hg and a coarse-adjust valve to regulate the sampling flowrate rate. A by-pass valve is in parallel with the vacuum pump to give fine flowrate control.

The vacuum pump shall have sufficient suction capacity to maintain the required isokinetic sampling rates. However, the suction capacity of the vacuum pump shall not be so large such that the flow capacities of the impinger train, dry gas meter and orifice meter will be exceeded during sampling.

7) Dry Gas Meter

A calibrated dry gas meter, equipped with inlet and outlet temperature measuring devices, shall be used to measure and indicate the total volume of gas sampled. The average of the meter inlet and outlet temperatures shall be used as the average dry gas meter temperature. The dry gas meter shall follow the leak-free vacuum pump in the sampling train. The dry gas meter shall be cleaned and calibrated periodically.

8) Orifice Meter

A calibrated orifice with an attached, inclined manometer should be used to measure and indicate the pressure drop used to calculate the isokinetic sampling flowrates. The orifice shall be cleaned and calibrated periodi-

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cally.

   b. Sampling Procedure

        Assemble the particulate matter sampling train as shown in Figure
9. Add the required amount of deionized or distilled water and silica gel to
the impinger train. Leak test the sampling train at the sampling site by
plugging the inlet to the filter holder and pulling a 15" Hg. vacuum. The
needle on the dry gas meter should not move. If the needle moves, a leakage
rate through the vacuum pump not in excess of 0.02 cfm (as measured by the
dry gas meter) at 15" Hg. is acceptable. Mark off the distances to each
specified sampling point on the sampling probe. Turn on the probe and filter
heating systems and allow the sampling apparatus to heat up. Screw the pipe
plug tightly into the pipe coupling to prevent in-leakage of ambient air.
Carefully insert the sampling probe apparatus into the stack through the hole
drilled in the pipe plug. Position the sampling nozzle at the first sampling
point closest to the far side of the duct or stack. Point the nozzle directly
into the approaching gas stream and secure the entire apparatus to the support
system. Start the vacuum pump and immediately adjust the sampling flowrate
to the required isokinetic sampling rate for that point. Sample each point
in the stack isokinetically for the specified length of time making the neces-
sary adjustments in the sampling flowrate as stack conditions change or as
the pressure drop across the filter changes. Read and record all instrument
readings (as required in Figure 10) at each sampling point every 2 minutes and
whenever adjustments are made to the sampling flowrate. It is essential that
the dry gas meter volume be read and recorded exactly at each 2 minute interval.
The stack gas velocity head and temperature, orifice meter pressure drop, gas
meter temperatures, impinger temperature and pump vacuum should then be read

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and recorded. When the traverse is completed, turn off the vacuum pump and record the instrument readings. Transfer the sampling apparatus to the other sampling port and follow the same procedure. When the second traverse is completed, remove the sampling apparatus from the stack and turn off the vacuum pump. Record the required instrument readings.

c. Sample Recovery

At the sampling site, disconnect the probe from the sampling train after it has cooled. Wash the interior surfaces of the nozzle-probe assembly with reagent grade acetone using a brush to remove the particulate matter that adheres to the walls of the nozzle-probe assembly and seal these washings in a numbered, polyethylene bottle.

If a cyclone is used prior to the filter, remove it from the sampling train. Seal the cyclone collection flask and set it aside for transportation to the laboratory. Wash the interior surfaces of the cyclone with reagent grade acetone using a rubber policeman to remove the particulate matter that adheres to the walls of the cyclone and add these washings to same bottle containing the nozzle-probe washings.

Remove the filter holder from the sampling train. Seal the inlet and outlet of the holder and set it aside for transportation to the laboratory. If the filter holder is required for subsequent testing the next day, the filter holder may be disassembled in a clean room at the plant site (but not at the actual sampling site). Carefully transfer the used filter to a numbered, pre-weighed petri dish and seal for transportation to the laboratory. Wash the interior surface of the front half of the filter holder with reagent grade acetone and add the washings to the same bottle containing the washings from the nozzle probe assembly and cyclone (if used). Seal the bottle for transportation to the laboratory.

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Measure and record the volume of water in the first three impingers to the nearest 0.5 ml. on the moisture analysis data sheet (Figure 11). Transfer the contents of the three impingers to a numbered, polyethylene bottle and seal. Rinse the first three impingers, all connectors and the back half of the filter holder with deionized or distilled water and add these washings to the same plastic bottle containing the contents of the impingers.

Transfer the silica gel from the fourth impinger to a numbered, polyethylene container. Use a rubber policeman to aid in removing the silica gel from the impinger. Seal the container for transportation to the laboratory.

Plant _____

Location _____

Test _____

Date _____

Operators _____

	Impinger Volume (ml.)	Silica Gel (gm.)
Final		
Initial		
Liquid Collected		gm.*
Total Volume Collected	V_{lc}	ml.

*$\dfrac{\text{weight of water}}{1 \text{ gm./ml.}}$ = volume of water, ml.

Figure 11. Particulate Matter Moisture Data Sheet

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d. Sample Analysis

1) Nozzle-Probe, Cyclone, Filter Holder Washings

In the laboratory, transfer the acetone washings obtained from the nozzle-probe assembly, the cyclone and filter holder to a tared glass beaker and evaporate to dryness at ambient temperature and pressure. Desiccate to a constant weight (nearest 0.5 mg). Record the results on the particulate matter analysis sheet shown in Figure 12 for each sampling test conducted.

2) Cyclone Collection Flask

In the laboratory, desiccate the particulate matter in the collection flask to a constant weight (to nearest 0.5 mg.) Record the result on the particulate matter analysis sheet.

3) Glass Fiber Filter

In the laboratory, carefully remove the filters from their holders or containers and desiccate to a constant weight (to nearest 0.5 mg.). Record each of the results on the particulate matter analysis sheet.

4) Impingers

In the laboratory, evaporate the contents of the impingers and the washings to dryness at $212^\circ F$. Desiccate to a constant weight (to nearest 0.5 mg.). Record this weight on the particulate matter analysis sheet. This weight of material shall not be included in the calculation of the total weight of particulate matter unless so specified by the Air Management Branch. Weigh the spent silica gel to the nearest gram. Record this result on the stack gas moisture data sheet.

Use equation (10) to correct the gas sample volume measured by the dry gas meter to reference conditions.

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Plant _____

Location _____

Test _____

Date _____

Operators _____

	Final Weight (mg.)	Tare Weight (mg.)	Weight of Particulate Matter (mg.)
Beaker Containing Washings from Nozzle, Probe, Cyclone (if used), Front Half Filter Holder			
Cyclone Collection Flask (if used)			
Glass Fiber Filter			
Beaker Containing* Impinger Contents and Washings, Back Half of Filter Holder			
	Total Weight of Particulate Matter M_p (mg.)		

*Not to be included in determination of the total weight of particulate matter (M_p) unless so specified by Air Management Branch.

Figure 12. Particulate Matter Analysis Sheet

$$(V_m)_{ref} = V_m \left(\frac{T_{ref}}{T_m}\right) \left(\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{ref}}\right)$$

$$(V_m)_{ref} = \left(17.71 \frac{^oR}{inches\ Hg}\right) \left(\frac{V_m}{T_m}\right) \left(P_{bar} + \frac{\Delta H}{13.6}\right) \qquad (10)$$

where

$(V_m)_{ref}$ =   Volume of gas through dry gas meter at reference conditions, ft.^{3}

V_m =   Volume of gas measured by dry gas meter at meter conditions (see Figure 10), ft.^{3}

T_{ref} =   Absolute temperature at reference conditions, 530^oR

T_m =   Average dry gas meter temperature (see Figure 10), ^oR.

P_{bar} =   Barometric pressure at the orifice, inches Hg

ΔH =   Average pressure drop across orifice (see Figure 10), inches H_2O

13.6   =   Conversion factor, $\dfrac{inches\ H_2O}{inches\ Hg}$

P_{ref} =   Absolute pressure at reference conditions, 29.92 inches Hg

Convert the volume of liquid condensed during the stack test to a volume of vapour at reference conditions using equation (11).

$$(V_w)_{ref} = \frac{V_{lc}}{453.59} \left(\frac{\rho_{H_2O}}{M_{H_2O}}\right) \left(\frac{R\ T_{ref}}{P_{ref}}\right)$$

$$(V_w)_{ref} = \left(0.0474 \frac{ft.^3}{ml}\right) V_{lc} \qquad (11)$$

where

$(V_w)_{ref}$ =   Volume of water vapour in gas sample at reference conditions, ft.^{3}

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V_{1c} = Total volume of liquid collected in impingers and silica

gel (see Figure 11), ml.

ρ_{H_2O} = Density of water, 1 gm./ml

M_{H_2O} = Molecular weight of water, $18 \frac{lb}{lb.mole}$

R   = Ideal gas constant, $21.83 \frac{inches\ Hg - ft.^3}{lb.mole - {}^oR}$

T_{ref} = Absolute temperature at reference conditions, 530^oR

P_{ref} = Absolute pressure at reference conditions, 29.92 inches Hg

453.59   = Conversion factor, $\frac{gm}{lb}$

Calculate the moisture content of the stack gas using equation

(12).

$$B_{wo} = \frac{(V_w)_{ref}}{(V_m)_{ref} + (V_w)_{ref}} \qquad (12)$$

where

B_{wo} = Proportion by volume of water vapour in the gas stream,

dimensionless

$(V_w)_{ref}$ = Volume of water vapour in the gas sample at reference

conditions (see quation 11), $ft.^3$

$(V_m)_{ref}$ = Volume of gas sample through the dry gas meter at reference

conditions (see equation 10), $ft.^3$

Calculate the emission rate of particulate matter using equations

(13) and (14).

$$C_p = (2.205 \times 10^{-6}) \frac{M_p}{(V_m)_{ref}} \qquad (13)$$

where

C_p = Concentration of particulate matter in stack gas on a dry

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basis at reference conditions, $\dfrac{\text{lb}}{\text{ft.}^3}$

M_p = Total amount of particulate matter collected (see Figure 12), mg.

$(V_m)_{ref}$ = Volume of gas sample through dry gas meter at reference conditions (see equation 10), ft.^{3}

2.205×10^{-6} = Conversion factor, $\dfrac{\text{lb.}}{\text{mg.}}$

$$ER_p = (C_p)(Q_s) \qquad\qquad (14)$$

where

ER_p = Emission rate of particulate matter from the stack on a dry basis at reference conditions, $\dfrac{\text{lb.}}{\text{hr.}}$

C_p = Concentration of particulate matter in stack gas on a dry basis at reference conditions, $\dfrac{\text{lb.}}{\text{ft.}^3}$

Q_s = Volumetric stack gas flowrate on a dry basis at reference conditions (see equation 3), $\dfrac{\text{ft.}^3}{\text{hr.}}$

e. Reporting Particulate Matter Test Results

1) Definition of a Test

A particulate matter sampling test shall be defined as the single composite result of simultaneous stack gas velocity, temperature and particulate matter concentration measurements made at the chosen sampling site at each specified point on 2 different traverses at 90° and the specified auxiliary measure-

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ments (stack gas velocity and temperature profile data, volumetric stack gas flowrate, stack gas composition and molecular weight, stack gas moisture content) required to calculate a stack emission rate.

2) Number of Tests

A minimum of three particulate matter sampling tests shall be conducted at the sampling site (not including preliminary traverses). Sampling at each point should not deviate by more than ±10% from isokinetic. That is, the ratio of the sampling nozzle velocity to the actual stack gas velocity (% isokinetic) for each point sampled must satisfy the expression.

$$90\% \leq I \leq 110\%$$

$$\%I = \frac{\left(\frac{DGMV}{t}\right) \left(\frac{1}{1-B_{wo}}\right) \left(P_{bar} + \frac{\Delta H}{13.6}\right) (T_s)}{0.3272 (N_d)^2 \left(\frac{T_{mi} + T_{mo}}{2}\right) (P_s) (U_s)} \times 100$$

where

DGMV = Volume of gas sample through dry gas meter at meter conditions for each point sampled, ft.^{3}

t = Sampling time for each point sampled, minutes

B_{wo} = Proportion by volume of water vapor in the gas stream (see equation 12), dimensionless

P_s = Absolute stack gas pressure (see equation 1), inches Hg

T_s = Absolute stack gas temperature for each point sampled, ^oR

T_{mi} = Dry gas meter absolute, inlet temperature for each point sampled, ^oR

T_{mo} = Dry gas meter absolute, outlet temperature for each point sampled, ^oR

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N_d = Inside diameter of sampling nozzle, inches

P_{bar} = Barometric pressure at the sampling site, inches Hg

ΔH = Pressure drop across orifice meter for each point sampled, inches H_2O

U_s = Stack gas velocity for each point sampled (see equation 2), ft./sec

0.3272 = Conversion factor

13.6 = Conversion factor, $\dfrac{\text{inches } H_2O}{\text{inches Hg}}$

Overall sampling results (obtained by averaging individual values of %I for each point sampled) shall not deviate by more than ±10% from isokinetic conditions for test results to be acceptable.

3) Final Report

All the data collected during each stack test and the subsequent calculations involving this data shall be presented in the test report. This includes the following:

(1) Preliminary traverse data and results

(2) Velocity traverse data sheets and results

(3) Volumetric stack gas flowrate results

(4) Stack gas composition data sheet and results

(5) Stack gas molecular weight results

(6) Stack gas moisture data sheet and results

(7) Particulate matter traverse data sheet, particulate matter analysis sheet and moisture data sheet and results.

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(8) Particulate matter emission rate results.

A description of the location of the sampling site, the flow disturbances present, the number and location of the sampling points, the sampling train and the difficulties that were encountered and how they were overcome shall be included in the report.

All pertinent data regarding plant production rates, products and pollution control equipment operation during the time of the tests shall be recorded and related to the measured emission rates and shall also be included in the report.

4) Witnessing of Stack Tests

Independent stack sampling investigations conducted by industrial plant personnel or private consulting organizations, the results of which will be sent to the Air Management Branch for consideration and evaluation, may be witnessed by a member of the Branch. The Branch shall require notification of pending stack tests well in advance (2-3 weeks) so that test dates can be arranged which are mutually convenient to the company, the stack testing firm and the Branch (should the Branch decide to witness the tests).

In addition, a brief, verbal description of the process to be tested and the procedures and equipment to be used should be presented to the Branch by the source testing supervisor of the sampling team at this time (2-3 weeks before tests).

5. Sulphur Dioxide

A gas sample is extracted from one sampling point near the center of the stack at a sampling site selected in accordance with Section E "Location of Sampling Site". The acid mist, including sulphur trioxide is separated from the sulphur dioxide which is measured by the barium-thorin titration method.

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The emission rate of sulphur dioxide is determined by multiplying the concentration of sulphur dioxide by the volumetric stack gas flowrate determined in accordance with Section 1 1. "Volumetric Stack Gas Flowrate." A minimum of three tests shall be required for each source to be sampled. The Air Management Branch may specify a proportional sampling and traversing technique if the emissions from a source vary significantly with time.

a. Instrumentation

Figure 13 illustrates the sulphur dioxide sampling train.

A continuous stack gas monitor may also be used to measure the concentration of sulphur dioxide in a duct or stack provided the Air Management Branch is notified of its pending use in advance of the test date.
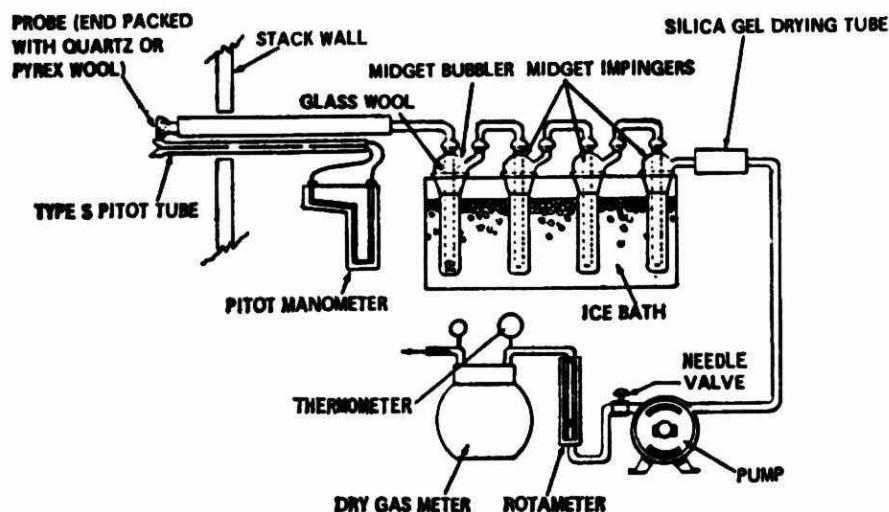
Figure 13. Sulphur Dioxide Sampling Train

1) Sampling Probe

The sampling probe shall be made of Pyrex glass tubing approximately 5 to 6 mm I.D. with an electrical heating system to prevent condensation in the probe. The end of the probe exposed to the stack gases shall be packed with fine quartz or Pyrex wool to remove particulate matter.

2) Impinger Train

The impinger train shall consist of three midget fritted impingers and one midget standard impinger all immersed in an ice bath to keep the temperature of the gases leaving the last impinger at 70°F or less. The top of the first midget fritted impinger shall be packed with glass wool. The first midget fritted impinger shall contain 15 ml. of 80% isopropanol solution. To prepare 80% isopropanol, mix 80 ml. of isopropanol with 20 ml. of distilled water.

The second and third midget fritted impingers shall contain 15 ml. of 3% hydrogen peroxide solution. To prepare 3% hydrogen peroxide solution, dilute 10 ml. of 30% hydrogen peroxide to 100 ml. distilled water. Prepare this solution fresh daily. The last midget impinger shall be left dry.

3) Drying Tube

A drying tube packed with 6 to 16 mesh, indicating type silica gel, shall be used to dry the gas sample.

4) Vacuum Pump

A leak free vacuum pump shall be used to continuously draw a sample of the stack gases through the sampling train.

5) Needle Valve

A needle valve shall be used to adjust the sampling flowrate through the sampling train.

6) Rotameter

A calibrated rotameter shall be used to indicate the instantaneous sampling flowrate through the sampling train.

7) Dry Gas Meter

A calibrated dry gas meter shall be used to measure the total volume of gas sampled. The dry gas meter shall be equipped with temperature measuring devices to measure and indicate the gas temperature at the meter inlet and outlet.

b. Reagents

1) Hydrogen peroxide solution, 3%. Prepare fresh daily by diluting 10 ml. of 30% hydrogen peroxide solution to 100 ml. with distilled water.

2) Isopropanol, 80%. Mix 80 ml. of isopropanol with 20 ml. of distilled water.

3) Perchloric acid, 70 - 72%. Mix one volume of acid with approximately four volumes of distilled water.

4) Thorin indicator. Dissolve 0.2 gm. of thorin, $\left[\text{1-(0-arsono}\right.$ phenyl azo)-2-naphthol-3;6- disulphonic acid, disodium salt$\left.\right]$, in 100 ml. of distilled water.

5) 0.01 N Barium perchlorate solution. Dissolve 1.95 gm. of $Ba(ClO_4)_2 \cdot 3H_2O$ in 200 ml. of distilled water, and dilute the solution to 1 liter with isopropanol. Standardize the barium perchlorate solution against a series of 10 ml. amounts of standardized sulphuric acid solutions, by following the procedure outlined below. The sulphate content of the standardized solutions should correspond closely with that of the stack sample solutions.

c. Sampling Procedure

Measure the atmospheric pressure at the sampling site with a baro-

meter to within 0.1 inches Hg. Assemble the sulphur dioxide sampling train as shown in Figure 13. Leak test the sampling train at the sampling site by plugging the probe inlet and pulling a 10 inches Hg. vacuum. The leakage rate shall not exceed 1% of the sampling rate. The final volume measured by the dry gas meter shall be correlated to account for this leakage rate. Screw the pipe plug tightly into the pipe coupling to prevent in-leakage of ambient air. Insert the heated sampling probe to the sampling point near the center of the stack through the hole drilled in the pipe plug and secure the probe. Sample at a constant rate of 0.075 cfm for at least 20 minutes. Record the data required in Figure 14 as the test progresses and at the end of the test. Remove the probe from the stack and disconnect it from the remainder of the sampling train. Drain the ice bath and purge the train by drawing ambient air through a charcoal filter system attached to the inlet of the impinger train for 15 minutes.

d. Sample Recovery

Disconnect the midget fritted impingers after purging. Discard the contents of the first midget fritted impinger. Pour the contents of the remaining three impingers into a polyethylene bottle. Rinse the three impingers and their connectors with distilled water and add the washings to the same polyethylene bottle for shipment to the laboratory.

e. Sample Analysis

In the laboratory transfer the contents of the bottle to a 100 ml. volumetric flask and dilute to the mark with distilled water. Pipette a 10 ml. aliquot of this solution into a 125 ml. Erlenmeyer flask. Add 40 ml. of isopropanol and 2 to 4 drops of thorin indicator. Titrate to a pink endpoint using 0.01 N barium perchlorate allowing 2 to 3 seconds between addition of drops of

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titrant near the endpoint. Carry a blank, acidified to an apparent pH of about 3.0 by the addition of perchloric acid, through the procedure for each test run.

Plant _____

Location _____

Test _____

Date _____

Barometric Pressure, Inches Hq _____

Operators _____

Time	Dry Gas Meter Volume (ft^3)	Dry Gas Meter Temperature $(^o F)$		Rotameter Reading $(ft^3/min.)$
		Inlet	Outlet	
		Average	Average	
	Total	Average		

Figure 14. Sulphur Dioxide Data Sheet

Use equation (15) to correct the sample volume measured by the dry gas meter to reference conditions (29.92 inches Hq., $70^o F$).

$$(V_m)_{ref} = V_m \; \left(\frac{T_{ref}}{T_m} \right) \left(\frac{P_{bar}}{P_{ref}} \right)$$

$$= 17.71 \; \frac{^oR}{\text{inches Hg}} \; \left(\frac{V_m \; P_{bar}}{T_m} \right) \tag{15}$$

where

$(V_m)_{ref}$ = Volume of gas sample through dry gas meter at reference conditions, $ft.^3$

V_m = Volume of gas sample through dry gas meter at meter conditions (see Figure 14), $ft.^3$

T_{ref} = Absolute temperature at reference conditions, $530 {}^oR$

T_m = Average absolute dry gas meter temperature (see Figure 14), ^oR

P_{bar} = Barometric pressure at the sampling site, inches Hg

P_{ref} = Absolute pressure at reference conditions, 29.92 inches Hg

Use equation (16) to calculate the sulphur dioxide concentration at reference conditions.

$$C_{SO_2} = \left(7.05 \times 10^{-5} \; \frac{\text{lb.-liter}}{\text{gm.-ml}} \right) \; \frac{N}{(V_m)_{ref}} \; (V_t - V_{tb}) \; \left(\frac{V_{soln.}}{V_a} \right) \tag{16}$$

where

C_{SO_2} = Concentration of sulphur dioxide on a dry basis at reference conditions, $\dfrac{\text{lb.}}{\text{ft.}^3}$

V_t = Volume of barium perchlorate titrant used for the sample, ml.

V_{tb} = Volume of barium perchlorate titrant used for the blank, ml.

N   = Normality of barium perchlorate titrant, $\frac{gm.\ equiv.}{liter}$

V_{soln} = Total solution volume of sulphur dioxide, 100 ml.

V_a = Volume of sample aliquot titrated, ml.

$(V_m)_{ref}$ = Volume of gas sample through dry gas meter at reference conditions (see equation 15), $ft.^3$

Use equation (17) to calculate the emission rate of sulphur dioxide at reference conditions on a dry basis.

$$ER_{SO_2} = C_{SO_2}\ Q_s \qquad (17)$$

where

ER_{SO_2} = Emission rate of sulphur dioxide on a dry basis at reference conditions, $\frac{lb.}{hr.}$

C_{SO_2} = Concentration of sulphur dioxide on a dry basis at reference conditions, $\frac{lb.}{ft.^3}$

Q_s = Volumetric stack gas flowrate on a dry basis at reference conditions (see equation 3), $\frac{ft.^3}{hr.}$

6.   Nitrogen Oxides

A grab sample of gas is collected from one sampling point near the center of the stack at a sampling site selected in accordance with Section E "Location of Sampling Site." The nitrogen oxides (except nitrous oxide) are collected in an evacuated flask containing a dilute sulphuric acid-hydrogen peroxide absorbing solution. The concentration of nitrogen oxides is determined colorimetrically using the phenoldisulphonic acid procedure. The emission rate

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of oxides of nitrogen (expressed as nitrogen dioxide) is determined by multiplying the concentration of oxides of nitrogen by the volumetric stack gas flowrate determined in accordance with Section I 1. "Volumetric Stack Gas Flowrate." A minimum of three tests shall be required for each source to be sampled.

a. Instrumentation

Figure 15 illustrates the nitrogen oxides sampling train. A continuous stack gas monitor may also be used to measure the concentration of nitrogen oxides in a duct or stack provided the Air Management Branch is notified of its pending use in advance of the test date.

1) Sampling Probe

The sampling probe shall be made of Pyrex glass tubing approximately 5 to 6 mm. I.D. with an electrical heating system to prevent condensation in the probe. The end of the probe exposed to the stack gases shall be packed with fine quartz or Pyrex wool to remove particulate matter.

2) Collection Flask

The collection flask shall be a 2 liter, calibrated Pyrex round bottom flask with a short neck and a 24/40 standard taper opening, protected against implosion or breakage by a foam encasement. To determine the volume of the collection flask and valve assembly used, fill the flask with water at room temperature, set the flask valve in the neck of the flask, and add water to fill the assembly to the bore of the stopcock. Transfer the entire volume of water contained in the flask and valve assembly, to a calibrated measuring cylinder, and record the volume found. The flask valve shall be a T-bore stopcock connected to a 24/40 standard taper joint. A temperature measuring device shall be inserted through the foam encasement against the

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flask to measure the flask temperature.

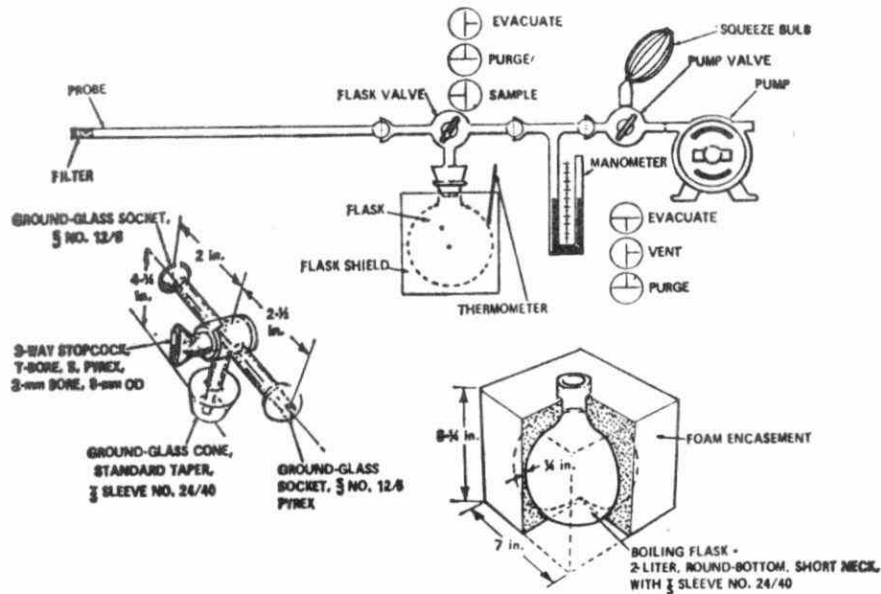Figure 15. Sampling Train for Oxides of Nitrogen

3) Pressure Gauge

A 36" vertical U-tube mercury manometer shall be used to measure
the flask pressure to within 0.1" Hg.

4) Vacuum Line

Tubing capable of withstanding a vacuum of 3" Hg. absolute pressure
with a T-connection and a T-bore stopcock shall be used.

5) Vacuum Pump

A vacuum pump capable of producing a vacuum of 3" Hg. absolute

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pressure shall be used to evacuate the collection flask.

6) Barometer

A barometer shall be used to measure the atmospheric pressure to within 0.1 inches Hg.

b. Reagents

1) Absorbing Solution

Add 2.8 ml. of concentrated sulphuric acid to 1 liter of distilled water. Mix and add 6 ml. of 30% hydrogen peroxide solution. Prepare a fresh solution weekly.

2) Sodium Hydroxide Solution

Prepare a 5% (W/V) solution in distilled water.

3) Sulphuric acid, concentrated.

4) Sulphuric acid, fuming, containing 15 to 18% of free sulphur trioxide.

5) Phenol, white.

6) Phenoldisulphonic Acid Solution

Dissolve 25 gm. of phenol in 150 ml of concentrated sulphuric acid, by heating on a steam bath. Cool, add 75 ml. of fuming sulphuric acid and heat on the steam bath for 2 hours. Store the solution in a dark, stoppered bottle.

7) Ammonium hydroxide, concentrated.

8) Potassium Nitrate Stock Solution

Dissolve 0.5495 gm. of potassium nitrate in distilled water and dilute to 1 liter. To prepare a working solution for calibration purposes, pipette 10 ml. of the stock solution into a 100 ml volumetric flask, and make up to volume with distilled water.

c. Sampling Procedure

Pipette 25 ml. of the absorbing solution into a collection flask.

Insert the flask valve stopper into the flask with the valve in the purge position. Assemble the sampling train as shown in Figure 15. Screw the pipe plug tightly into the pipe coupling to prevent in-leakage of ambient air. Insert the sampling probe to the sampling point near the center of the stack through the hole drilled in the pipe plug. Turn the flask valve and the pump valves to their "evacuate" positions. Evacuate the flask to at least 3 inches Hg. absolute pressure. Turn the pump valve to its "vent" position and turn off the pump. Check the manometer for any fluctuation in the mercury level. If there is a visible change over the span of one minute, check for leaks. Record the inital volume, temperature, and barometric pressure as required in Figure 16. Turn the flask and pump valves to their "purge" positions. Attach a double acting rubber squeeze bulb and purge the probe and the vacuum line. Turn the pump valve to its "vent" position. Turn the flask valve to its "sample" position and allow sample to enter the flask for about 15 seconds. After collecting the sample, turn the flask valve to its "purge" position and disconnect the flask from the sampling train. Shake the flask for 5 minutes.

d. Sample Recovery

Let the flask set for a minimum of 16 hours and then shake the contents for 2 minutes. Connect the flask to a mercury filled U-tube manometer, open the valve from the flask to the manometer, and record the flask pressure and temperature along with the barometric pressure as required in Figure 16. Transfer the flask contents to a polyethylene bottle. Rinse the flask with two portions of distilled water and add the rinse water to the sample. Add sodium hydroxide dropwise to the sample until alkaline to litmus paper.

e. Sample Analysis

In the laboratory, pour the contents of the bottle into a 250 ml.

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Plant _____

Location _____

Test _____

Date _____

Operators _____

Flask Initial Volume (ml)	Flask Initial Pressure (inches Hg.)	Flask Initial Temperature (^0F)	Barometric Pressure (inches Hg)	Flask Final Pressure (inches Hg)	Flask Final Temperature (^0F)	Barometric Pressure (inches Hg)

Figure 16. Nitrogen Oxides Data Sheet

beaker. Rinse the bottle with distilled water and add the washings to the beaker. Evaporate the solution to dryness on a steam bath and then cool. Add 2 ml. of phenoldisulphonic acid solution to the dried residue and triturate thoroughly using a glass rod, so that the solution contacts all the residue. Add 1 ml. of distilled water, four drops of concentrated sulphuric acid, and heat the beaker contents on a steam bath for 3 minutes with occasional stirring. Allow to cool, add 20 ml. distilled water mixing well by stirring.and add concentrated ammonium hydroxide dropwise with stirring until the solution becomes alkaline to litmus paper. Transfer the beaker contents into a 100 ml. volumetric flask, wash the beaker three times with 4 to 5 ml. portion of distilled water, and add the washings to the flask. Make up to 100 ml. with distilled water and mix thoroughly. Measure the absorbance of the sample at 420 nm., in a spectrophotometer, setting the absorbance of the blank solution to zero. If the sample contains solids, filter or centrifuge a portion, and use the clear portion for the colorimetric determination. If the absorbance reading falls outside the range of calibration, dilute the sample and the blank with equal suitable amounts of distilled water, to bring the reading within the range.

Add varying amounts of working standard potassium nitrate solution and sodium hydroxide solution dropwise to each in the range of 0.0 to 15.1 ml. to a series of beakers. Add 25 ml. of absorbing solution and dropwise, sodium hydroxide solution, to each beaker until the contents become alkaline to litmus paper. Follow the procedure given above to obtain a calibration curve of μg of nitrogen dioxide versus absorbance against which to assess the amount of nitrogen dioxide in the stack gas samples.

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Use equation (18) to correct the sample volume to reference conditions.

$$V_{sc} = \frac{T_{ref} \, (V_f - V_a)}{P_{ref}} \left(\frac{P_f - P_{H_2O}}{T_f} - \frac{P_i}{T_i} \right)$$

$$V_{sc} = 17.71 \, \frac{^\circ R}{\text{inches Hg.}} \, (V_f - 25) \left(\frac{P_f - P_{H_2O}}{T_f} - \frac{P_i}{T_i} \right) \tag{18}$$

where

V_{sc} = Sample volume on a dry basis at reference conditions, ml.

T_{ref} = Absolute temperature at reference conditions, $530^\circ R$

P_{ref} = Absolute pressure at reference conditions, 29.92 inches Hg.

V_f = Volume of flask and flask valve, ml.

V_a = Volume of absorbing solution, 25 ml.

P_f = Final absolute pressure of flask, inches Hg.

P_{H_2O} = Partial pressure of water, in inches Hg. at temperature T_f

P_i = Initial absolute pressure of flask, $^\circ R$

T_f = Final absolute temperature of flask, $^\circ R$

T_i = Initial absolute temperature of flask, $^\circ R$

Use equation (19) to calculate the concentration of nitrogen oxides on a dry basis at reference conditions.

$$C_{NO_X} = 6.2 \times 10^{-5} \, \frac{\text{lb/ft}^3}{\mu g/ml.} \left(\frac{m}{V_{sc}} \right) \tag{19}$$

where

C_{NO_X} = Concentration of nitrogen oxides as NO_2 on dry basis at reference conditions, $\dfrac{lb}{ft^3}$

m   = Mass of NO_2 in gas sample, μg

V_{sc} = Sample volume on a dry basis at reference conditions (see equation 18), ml.

Use equation (20) to calculate the emission rate of nitrogen oxides on a dry basis at reference conditions.

$$ER_{NO_X} = C_{NO_X} \ Q_s \qquad\qquad (20)$$

where

ER_{NO_X} = Emission rate of nitrogen oxides as NO_2 on a dry basis at reference conditions, $\dfrac{lb.}{hr.}$

C_{NO_X} = Concentration of nitrogen oxides as NO_2 on a dry basis at reference conditions (see equation 19), $\dfrac{lb}{ft^3}$

Q_s = Volumetric stack gas flowrate on a dry basis at reference conditions (see equation 3), $\dfrac{ft^3}{hr}$

October 31st, 1974.

Gentlemen:

In many source testing cases, the particulate matter loadings are very low and handling losses are introducing large relative errors. The catch then does not represent the actual emission.

Hence, Technology Development & Appraisal recommends that the consultant either catches a minimum of 25 milligrams of particulate or sample at least 120 SDCF of the stack gas. This is our interpretation of the Ontario Source Code which specifies the minimum volume of gas to be collected for a particulate test, as 60 SDCF (29.92 inches of Hg and 70°F). However, a larger sample may be required as dictated by analytical method of a specific compound.

Secondly, we recommend that the consultants present their data in a uniform format as shown in the attached Appendixes. At the same time, we must emphasize that the original data sheets should still be included in the report for our perusal.

Please do not hesitate to contact us with any questions.

Yours very truly,

Dino Mozzon

Dino Mozzon, P. Eng.,
Technology Development
& Appraisal Section,
Air Resources Branch.

DM/mll

Attach.

APPENDIX

To best illustrate the procedure by which the field data
is tabulated into the prescribed format, example test data will
be used.

The hypothetical field and lab data for a particulate
test is set out on pages 4 and 5 in this Appendix. The data reported
is typically that from an EPA train and is created for the convenience
of this discussion.

The field sheet information is fairly extensive and the data
seems to be taken conscientiously. What is missing is the last impinger
exit temperatures. (The operator never bothered to take them. In
his opinion, it took too much time and trouble to record the values.
However, his control box had overheated before because the impinger
box stopcock was not closed). Also, notice other important information
on this sheet.

His first reading is at time 0 minutes. Other samplers some-
times take the first reading at time equal 3 minutes and record the
initial dry gas volume somewhere on the page. Each way is purely
arbitrary. However, the first method must be utilized in order to
fill out the subsequent prescribed forms. The second noticeable
point is the poor segregation of the data from one traverse to another.
The value in the meter volume column, 171.18 ft^3, is both the end
volume of the first traverse and, also the initial volume of the second.
Although the test is cumulative, filters and impingers may be changed
between traverses, necessitating a leak test. By data logging the
traverses in "units", more flexibility will be available for the
samplers, and also makes for easier reading.

Page 5 shows the laboratory analysis results for the test.
This sampler chose to weigh the impinger, before and after the test,

by triple beam balance. The lab data was obtained by procedures described in the Ontario Source Code.

The two sheets lack just three data, which if known, make it possible to completely evaluate this test. These are: the pitot tube coefficient, the dry gas meter correction factor and the gas composition. Assuming that this information is available (and it should), one can now fill out the set of prescribed forms which start on Page 6.

Notice that the first page of the set is not just applicable for particulate tests. It can be slightly modified to cover all types of testing, be it particulate or acid mist. For example, suppose one is dealing with heavy metal emissions and their composition in the dust, another column can be added at the bottom of the sheet which would show the analysis breakdown.

Page 2 of Set 1 has the second type of form which is to be completed. This form contains only the information which will quantify the volumetric flowrate and determine isokinetic rates. The other data contained in the field sheet is just as important. However, it is not acted upon mathematically.

Three additional statements should be made about this last form. First, since there isn't any reference to traverse point or number, care must be taken in order to transcribe the data in an exact manner. Second, if one is using a temperature compensating dry gas meter, place $70^{o}F$ in the two appropriate columns. And thirdly, the dry gas meter volume value taken at the end of a traverse, is not considered a "complete" reading. The total number of readings

is equivalent to: the number of readings per point X the total number of sampling points. In our example case, the sampling time per point is 6 minutes and a reading taken every 3 minutes. There is a total of 9 sampling points. As a result, the total number of readings is 9 X 2 = 18. All columns except that for the gas meter volume have 18 numbers, and 6 per traverse. Notice that the meter volume column has 7 numbers per traverse.

FIELD SAMPLING DATA SHEET CHART

Plant __ABC, SMALLTOWN__
Location __Y BAGHOUSE EXIT__
Operator __J.D., B.L., C.D__
Date __14/08/74__
Run No. __PRELIM__
Sample Box No. _____
Control Module No. __2__
Meter (ΔH@) __2·1__
C Factor __1·05__

Schematic of Stack

26"
17"

.3	.2	.1
.6	.5	.4
.9	.8	.7

N
W — E
S
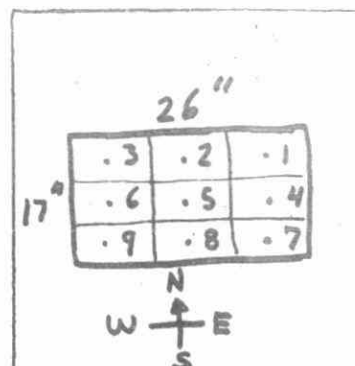
Cross Section

Ambient Temp. (°F.) __45__
Barometric Pres. (in. Hg.) __28.97__
Assumed Moisture (%). __2.0__
Heater Box Setting (°F). __250__
Probe Length (in.). __60__
Nozzle Diameter (in.). __·25__
Nozzle Area (Sq. in.). _____
STATIC PRESSURE __+·1 "H₂O__

Traverse Point Number	Sampling Time (θ) Min.	Stack Temp. Ts (°F)	Velocity Head (ΔP$_s$)	Velocity (Ft./sec)	Orfice Pressure Diff. (ΔH) in. H₂O	Gas Sample Volume (Vm) Cu. Ft.	Gas Temperature At Dry Gas Meter Inlet (Tm in.) °F	Outlet (Tm out) °F	Sample Box Temp. °F	Probe Temp. (°F)	VAC.
1	0	178	0·25		0·55	164·27	55	48	250	250	3
	3	180	0·23		0·52	165·70	60	48			3
2	6	180	0·12		0·27	167·15	60	50			2
	9	183	0·09		0·20	168·30	60	50			2
3	12	183	0·07		0·17	169·30	60	50			2
	15	183	0·07		0·17	170·23	61	50			2
4	18	180	0·18		0·40	171·18	64	51			3
	21	179	0·18		0·40	172·40	67	52			3
5	24	184	0·07		0·17	173·70	67	53			2
	27	184	0·06		0·15	174·70	65	51			2
6	30	182	0·04		0·10	175·58	64	51			1
	33	180	0·04		0·10	176·40	64	51			1
7	36	178	0·23		0·52	177·10	67	55			3
	39	178	0·23		0·52	178·60	68	54			3
8	42	180	0·16		0·35	180·08	68	55			2
	45	180	0·16		0·35	181·34	67	54			2
9	48	179	0·09		0·20	182·54	65	55			2
	51	179	0·10		0·23	183·58	64	55			2
	54					184·61					
Total							Avg:	Avg:			
Average							Average				

PLANT ABC, SMALLTOWN

DATE 14/08/74

LOCATION Y BAG HOUSE EXIT

OPERATORS J.O., B.L., C.O.

TEST PRELIM

ANALYST J.D.

MOISTURE DATA

	FINAL WEIGHT (gm.)	TARE WEIGHT (gm.)	WEIGHT OF MOISTURE (gm.)
IMPINGER # 1	685.5	685.0	.5
IMPINGER # 2	677.5	676.0	1.5
IMPINGER # 3	520.0	519.0	1.0
IMPINGER # 4	757.0	753.0	4.0
TOTAL			7.0
MOISTURE VOLUME			7.0 ml.

PARTICULATE DATA

	FINAL WEIGHT (gm.)	TARE WEIGHT (gm.)	WEIGHT OF PARTICULATE (gm.)
FILTER	.7235	.7009	.0226
BEAKER WITH (PROBE - NOZZLE - ~~CYCLONE~~) WASHINGS	110.2863	110.2618	.0245
CYCLONE FLASK	—	—	—
BEAKER WITH (IMPINGER FILTER-HOLDER) CONTENTS AND WASHINGS			.0121
TOTAL (gm.)			
PARTICULATES IN (mg.)			

COMPANY **ABC**   CITY **SMALLTOWN**

Test Type **PARTICULATE**   Date **14/08/74**

Location **Y BAGHOUSE EXIT**

Test Number **PRELIM**

Barometric Pressure **28.97**   inches Hg.

Stack Static Pressure **+.1**   inches, H_2O

Pitot Tube Coefficient **.81**

Dry Gas Meter Correction Factor **.99**

Nozzle Diameter **.25** inches

Stack Diameter or Dimensions **17 x 26** inches

Average Gas Composition **.2** %CO_2, **20.0**%O_2, **0.0** %CO

Total Readings **18**   Time Between Readings **3 min**

Points/Traverse **3**   No. of Traverses **3**

Condensed Water **3** gms

Water Caught by Drying Agent **4** gms

Particulate Weight In:

      Probe **24.5** mg

      Cyclone **0** mg

      Filter **22.6** mg

      Impinger **12.1** mg

Pg **1**

Set **1**

ΔP ORIFICE In. H₂0	ΔP PITOT In. H₂0	Ts STACK Temp. °F	Tmi METER Temp. °F In	Tmo METER Temp. °F Out	Vm GAS METER Volume ft³
·55	·25	178	55	48	164·22
·52	·23	180	60	48	165·70
·27	·12	180	60	50	167·15
·20	·09	183	60	50	168·30
·17	·07	183	60	50	169·30
·17	·07	183	61	50	170·23
					171·18
·40	·18	180	64	51	171·18
·40	·18	179	67	52	172·40
·17	·07	184	67	53	173·70
·15	·06	184	65	51	174·70

Pg. 2

Set 1

Δ P ORIFICE In. H₂O	Δ P PITOT In. H₂O	Ts STACK Temp. °F	Tmi METER Temp. °F In	Tmo METER Temp. °F Out	Vm GAS METER Volume ft³
.10	.04	182	64	51	175.58
.10	.04	180	64	51	176.40
					177.10
.52	.23	178	67	55	177.10
.52	.23	178	68	54	178.60
.35	.16	180	68	55	180.08
.35	.16	180	67	54	181.34
.20	.09	179	65	55	182.54
.23	.10	179	64	55	183.58
					184.61

Pg. __3__

Set __1__